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AN INTERNATIONAL COMPARISON OF TEMPERATURE SCALES BETWEEN 660° AND 1,063° C.

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ABSTRACT

This paper reports an intercomparison of the termperature scales (in the range 660° to 1,063° C.) in use at the National Physical Laboratory, the Physikalisch-Technische Reichsanstalt, and the Bureau of Standards since 1927. It is shown that the methods used in realizing the International Temperature Scale have yielded results differing by as much as 0.7° C. at 850° C. due primarily to a difference of 0.4° C. at the freezing point of silver, one of the basic fixed points of the International Temperature Scale. After exchanging samples of silver and thermocouples the various scales have been brought into agreement, within 0.1° C., at all points in the range covered.

CONTENTS

I. INTRODUCTION

Since the adoption of the International Temperature Scale in 1927 by the Seventh General Conference of Weights and Measures, representing 31 nations, the temperature determinations of practically the entire world have been based for the first time in history upon a common set of definitions and specifications. In the definition of the International Temperature Scale values are assigned to selected fixed points, instruments are specified to be calibrated at these fixed points, and forms of equations are specified for obtaining values other than the fixed points. To a very limited degree the experimental procedure to be followed in calibrating the instruments at the fixed points is also specified.

The fact that two standardizing laboratories base their temperature determinations on the International Temperature Scale leads to the presumption but does not of itself insure that the results obtained with instruments calibrated in one of these laboratories will agree with those obtained with instruments calibrated in the other. Since the fixed points of the scale are the temperatures at which either the solid and liquid phases or the liquid and vapor phases of pure materials are in equilibrium, appreciable differences in the purity of the materials actually used, or differences in experimental technique, may lead to constant differences, which can best be determined by having all the laboratories in question calibrate a given instrument or preferably a group of instruments.

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Arrangements have been made by the national laboratories of Great Britain, Germany, and the United States to make intercomparisons through an exchange of instruments calibrated in each laboratory according to its regular procedure for realizing the International Temperature Scale in practice. Since three types of instrument—the resistance thermometer, the thermocouple, and the optical pyrometer—are required to cover the entire range of this scale, the work has naturally been divided into three parts. The part covering that portion of the scale which is based on the indications of a thermocouple has now been completed and is the subject of this paper. The other two parts of the work will be published subsequently.

II. DEFINITION OF SCALE FROM 660° TO 1,063° C.[3]

From 660° C. to the gold point, the temperature t is deduced from the electromotive force e of a standard platinum *v.* platinum-rhodium thermocouple, one junction of which is kept at a constant temperature of 0° C. while the other is at the temperature t defined by the formula

$$e=a+bt+ct^2$$

The constants a, b, and c are to be determined by calibration at the freezing point of antimony, and at the silver and gold points.

The silver and gold points are defined as 960.5° and 1,063.0° C., respectively, but since the antimony point lies in the range in which temperatures are defined by platinum resistance thermometers, the freezing point of the antimony to be used is determined by resistance thermometer measurements.

III. METHODS AND RESULTS

Each of the three laboratories participating in the present work furnished two standard platinum to platinum-10 percent rhodium thermocouples. The data concerning these thermocouples and the metals used in the calibrations are given in tables 1 and 2.

The observations obtained in the three laboratories are summarized in tables 3 and 4.

After each of the laboratories had made measurements with all the thermocouples, the results showed significant discrepancies at the freezing point of silver, and further work was undertaken to determine the cause of these discrepancies.

Since the silver originally used at the Bureau of Standards was found to contain 0.069 percent impurities, a new lot of silver was obtained from the United States Bureau of the Mint. This silver is of the quality known as "inquartation silver", which contained only 0.005 percent lead, 0.002 percent copper, and 0.001 percent iron.

TABLE 1.—*Data on thermocouples used in intercomparison of temperature scales*

Thermocouples supplied by—	Thermocouples manufactured by—	Designated—	Preliminary treatment	Type of protection tube
Bureau of Standards	Bureau of Standards	G_1 and G_2	Annealed 6 hours at 1,500° C.	Porcelain.
National Physical Laboratory.	Johnson, Matthey & Co.	P_{16} and P_{17}	Annealed 1 hour at 1,500° C.	Silica.
Physikalisch-Technische Reichsanstalt.	Heraeus	$D_{3,024}$ and $D_{3,026}$	Annealed 5 minutes at 1,200° C.	Porcelain.

[3] Proc. Seventh General Conference of Weights and Measures. 1927, p. 56. Text in Annex IV, p. 94. B.S. Jour. Research, vol. 1, p. 635, 1928.

TABLE 2.—*Data on metals used in primary calibration of thermocouples*

Metal	Prepared by—	Purity	Freezing point [1]	Crucible material	Method of protection from oxygen	Depth of immersion of thermocouple
BUREAU OF STANDARDS						
			° C.			cm
Gold	U.S. Bureau of the Mint	99.99 (?)	1,063.0	Graphite (Acheson)		11
Silver (old)	do	99.931	960.5 (?)	do	Covered with flake graphite	11
Silver (inquartation)	do	99.992	960.5	do	do	11
Antimony	Schering-Kahlbaum A.G	99.96 (?)	[2] 630.53 [3] 630.47	do	do	11
Zinc	New Jersey Zinc Co	99.992	419.50	do	do	11
NATIONAL PHYSICAL LABORATORY						
Gold	Johnson Matthey & Co	99.99 (?)	1,063.0	Porcelain (Marquardt)		9
Silver	do	99.99	960.5	Silica	Melted in vacuo	13
Antimony	Schering-Kahlbaum A.G	99.97	630.42	Graphite	Covered with powdered graphite	11
Zinc	New Jersey Zinc Co	99.97	419.43	do	do	8
PHYSIKALISCH-TECHNISCHE REICHSANSTALT						
Gold (1928)	Heraeus		1,063.0			(4)
Gold (1931)	Gold- und Silberscheideanstalt	99.99	1,063.0	Porcelain		7
Silver	Heraeus	99.99	960.5	Graphite (Acheson)	Graphite cover	9
Antimony (1928)	Schering-Kahlbaum A.G		630.35	Graphite	do	11
Antimony (1931)	do	99.97	630.48	do	do	11
Zinc	do	99.9	419.45	do	do	10

[1] The values for the freezing points of gold and silver are defined. Those for antimony and zinc are determined by use of platinum resistance thermometer.
[2] In 1929.
[3] In 1931.
[4] Wire method.

TABLE 3.—*Summary of observations*

Laboratory	Year	Emf in microvolts (cold junctions at 0° C.)					
		$D_{3,024}$	$D_{3,026}$	G_1	G_2	P_{16}	P_{17}
GOLD POINT, 1,063.0° C.							
P.T.R	1928	10, 256	10, 257				
B.S	1929	10, 256. 0	10, 257. 3	10, 307. 8	10, 312. 7	10, 316. 9	10, 314. 7
N.P.L	1930	10, 254	10, 253. 5	10, 307. 5	10, 312	10, 316	10, 314
P.T.R	1931	10, 261	10, 257	10, 305	10, 314	10, 314	10, 314
B.S	1931			10, 307. 3	10, 313. 0	10, 313. 2	10, 312. 0
P.T.R	1931		10, 258				
SILVER POINT, 960.5° C.[1]							
P.T.R	1928	9, 082	9, 080				
B.S	1929	9, 075. 5	9, 075. 7	9, 117. 5	9, 121. 9	9, 124. 7	9, 122. 8
N.P.L	1930	9, 077. 5	9, 074	9, 126. 5	9, 129. 5	9, 127. 5	9, 128. 5
P.T.R	1931	9, 078	[2] 9, 064	9, 117	9, 123	9, 121	9, 124
B.S	1931			9, 117. 3	9, 121. 9	9, 121. 0	9, 119. 9
P.T.R	1931		[3] 9, 080				
B.S	1931			9, 118. 2	9, 121. 8		
B.S	1931			[4] 9, 123. 5	[4] 9, 127. 0		
ANTIMONY POINT, 630.50° C.[5]							
P.T.R	1928	5, 513. 5	5, 512. 5				
B.S	1929	5, 512. 1	5, 512. 1	5, 537. 3	5, 539. 3	5, 537. 3	5, 535. 8
N.P.L	1930	5, 514. 8	5, 513. 8	5, 536. 8	5, 539. 8	5, 535. 8	5, 536. 8
P.T.R	1931	5, 512. 2	5, 512. 2	5, 540. 2	5, 541. 2	5, 536. 2	5, 537. 2
B.S	1931			5, 536. 7	5, 539. 4	5, 535. 6	5, 534. 4
ZINC POINT, 419.45° C.[6]							
P.T.R	1928	3, 422. 5	3, 422. 1				
B.S	1929	3, 423. 2	3, 423. 3	3, 437. 4	3, 438. 1	3, 435. 3	3, 434. 4
N.P.L	1930	3, 425. 2	3, 424. 2	3, 437. 7	3, 438. 2	3, 436. 7	3, 436. 2
P.T.R	1931	3, 424	3, 419	3, 437	3, 438	3, 434	3, 434
B.S	1931			3, 437. 0	3, 438. 0	3, 434. 1	3, 433. 4

[1] Additional measurements with other thermocouples at the B.S. and the P.T.R. showed that the emf at the freezing point of the inquartation silver was 5.5 μv higher than that of the 1st lot of B.S. silver and 3.5 μv higher than that of the P.T.R. silver.
[2] This thermocouple was found to be inhomogeneous after this measurement.
[3] This value was obtained after annealing this thermocouple for 1 minute at 1,200° C.
[4] These values were obtained using a new lot of silver. (See p. 2.)
[5] The freezing points of the various samples of antimony ranged from 630.35° to 630.53° C., but all values in this table have been adjusted to 630.50° C.
[6] The freezing points of the various samples of zinc ranged from 419.43° to 419.50° C., but all values in this table have been adjusted to 419.45° C.

TABLE 4.—*Average emfs of thermocouples*

Freezing point	Temperature	Average emf in microvolts		
		P.T.R.	N.P.L.	B.S.
	° *C.*			
Gold	1, 063. 0	10, 293. 8	10, 292. 8	10, 293. 7
Silver (first lot)	960. 5	[1] 9, 107. 5	9, 110. 6	[2] 9, 105. 8
Silver (second lot)[3]	960. 5	9, 111. 0		9, 111. 3
Antimony	630. 50	5, 530. 0	5, 529. 6	5, 528. 7
Zinc	419. 45	3, 431. 1	3, 433. 0	3, 431. 7

[1] The value 9,064 obtained with $D_{3,026}$ in 1931 is not included in this average.
[2] This value was obtained with the silver which contained 0.069 percent impurities.
[3] The values given here were obtained by applying corrections to the values in the line above.

The following conclusions have been drawn from these experiments:

(*a*)[4] The freezing point of the "inquartation silver" is 0.5° C. (5.5 μv) higher than that of the silver previously used at the Bureau of Standards and listed as "first lot" in table 4.

(*b*)[5] The freezing point of the "inquartation silver" is 0.3° C. (3.5 μv) higher than that of the Heraeus silver listed in table 2.

(*c*)[4] The freezing point of the "inquartation silver" is within 0.01° C. (0.1 μv) of that of a sample (kindly loaned to us by Dr. A. L. Day) used in the gas thermometer work of Day and Sosman which led to the acceptance of 960.5° C. as the freezing point of pure silver.

(*d*)[4] The freezing point of any particular lot of silver protected from access of oxygen by graphite is within 0.05° C. (0.6 μv) of that of the same silver in porcelain in vacuo (pressure 0.03 to 0.005 mm Hg).

From this it is evident that the results of the Bureau of Standards and of the Physikalisch-Technische Reichsanstalt given in tables 3 and 4 for the first lots of silver should be increased 5.5 and 3.5 μv, respectively. When this is done the observations of the three laboratories at the freezing point of silver are brought into exceedingly close agreement.

The differences between the thermoelectric temperature scales of the various laboratories based on both the old and new silver are given in detail in table 5.

IV. SUMMARY

The results indicate that previous to this intercomparison the maximum difference in the range 660° to 1,063° C. of the temperature scales of the National Physical Laboratory and the Bureau of Standards has been 0.7° C. at 850° C. due primarily to a difference of 0.42° C. at the freezing point of silver. The maximum difference between the scales of the National Physical Laboratory and the Physikalisch-Technische Reichsanstalt has been 0.4° C. at 850° C., due primarily to a difference of 0.27° C. at the freezing point of silver. After exchanging samples of silver these differences have been reduced to about 0.1° C. The mean values obtained with six thermocouples at the three National Laboratories are in agreement to this extent. The results obtained with a single couple may differ to a greater extent, possibly several tenths of a degree. Such differences are presumably to be attributed to small inhomogeneities in the couples and to lack of temperature uniformity in the furnace and are therefore of the nature of accidental errors.

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[4] B.S. Jour. Research, vol. 10 (RP557), p. 661, May 1933.
[5] Zeits. für Instrumentenkunde, vol. 52, p. 201, 1932.

TABLE 5.—*Average temperature-emf relation for thermocouples*

Temperature °C.	Emf in microvolts				
	N.P.L.	P.T.R. based on inquartation silver	P.T.R. based on P.T.R. silver	N.B.S. based on inquartation silver	N.B.S. based on old silver
419.45	3,433.0	3,431.1	3,431.1	3,431.7	3,431.7
630.50	5,529.6	5,530.0	5,530.0	5,528.7	5,528.7
660.00	5,835.7	5,836.0	5,834.8	5,835.0	5,833.1
700.00	6,255.2	6,255.4	6,252.8	6,254.8	6,250.7
750.00	6,786.7	6,786.7	6,782.9	6,786.5	6,780.4
800.00	7,326.0	7,326.0	7,321.4	7,326.1	7,318.9
850.00	7,873.2	7,873.3	7,868.5	7,873.6	7,866.0
900.00	8,428.4	8,428.5	8,424.0	8,428.9	8,421.7
950.00	8,991.4	8,991.7	8,988.0	8,992.0	8,986.2
960.50	9,110.6	9,111.0	9,107.5	9,111.3	9,105.8
1,000.00	9,562.2	9,562.8	9,560.4	9,563.0	9,559.3
1,050.00	10,141.0	10,141.9	10,141.4	10,141.9	10,141.0
1,063.00	10,292.8	10,293.8	10,293.8	10,293.7	10,293.7

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